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COST-BENEFIT EFFECTS OF CONVERSION TO SI UNITS IN HEALTH PHYSICS

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ABSTRACT

To evaluate the potential hazards associated with the introduction of new units for dose, activity and exposure, a study has been conducted to identify areas of concern. Three types of questionnaires have been sent to health physicists, professionals in nuclear medicine and the nuclear instrument industry. There is widespread opposition to the changes and a high proportion of the respondents anticipate hazards to patients and personnel during the transition period. No numerical estimate could be obtained for the actual magnitude of this risk, which is largely associated with relearning lapses and fatigue. Nevertheless, since it is anticipated that the change-over to SI units will be mandatory, a rapid change-over period is advocated to minimize confusion, accompanied by conversion of digital instruments and intensive familiarization procedures, such as seminars and official publications containing conversion data.

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COST-BENEFITS EFFECTS OF CONVERSION TO SI UNITS IN HEALTH PHYSICS

INTRODUCTION

There is a general move in scientific and technical activities throughout the world to move to a common system of units, specifically the Système Internationale (SI) group of units, based on the meter, second, kilogram and ampere.[1,2] With few exceptions, the United States among them, all major countries have legally adopted these units for use in all commercial and technical activities. In the U.S. these units have been adopted by Congress (National Metric Conversion Act of 1975) but are not mandatory, though increasingly trade groups and professional organizations have pressed for conversion to SI units within their respective activities. A U.S. Metric Board has been set up within the Department of Commerce to assist in this transition but is has advisory responsibilities only. However, in view of the heavy involvement of U.S. industry in international trade, there appears to be a strong expectation that a general, obligatory switch to SI units is inevitable.

In the field of Health Physics metric units have been in common use from the beginning and most practitioners are familiar with them. However, in common with most physical measurements they have been based on the c.g.s. (centimeter, gram, second) system and its derived units, such as ergs, calories and dynes; hence a change to SI units will require some minor conversions. It is the specialized radiation units, which have specific definitions and which are derived from the basic units, where some difficulties are anticipated and strong objections have been voiced against any change. A good review of the arguments for and against these changes has been presented by Burns.[3]

The units involved in radiation work are:

a. The unit of activity, with the <u>becquerel</u> replacing the <u>curie</u>;

$$1\ \text{Bq} = 27.03\ \text{pCi}$$

b. The unit of exposure, the <u>roentgen</u> being replaced by coulomb/kg, with a strong recommendation to drop the concept from everyday practice;

$$1\ \text{C/kg} = 3.88\ \text{kR}$$

c. The unit of absorbed dose, the <u>gray</u> replacing the <u>rad</u>;

$$1\ \text{Gy} = 100\ \text{rad}$$

d. The unit of dose equivalent, with the <u>sievert</u> replacing the <u>rem</u>;

$$1\ \text{Sv} = 100\ \text{rem}.$$

Apart from the normal instinctive reaction against any change in familiar units, there has been some concern that the change in these units may lead to unacceptable costs and some apprehension that unfamiliarity or momentary lapses may lead to unintended overexposures to radiation of hospital staff, patients or radiation workers. The present project has been conducted to investigate these problems, to establish their significance, and to discuss any questions of general policy that may arise in connection with this change in units in the fields of health physics and radiation applications. A similar review has been done in Great Britain[4,5] where parallel concerns have been expressed.

The project has been undertaken with the premise that the change-over in units is bound to occur sooner or later and that it is important to be prepared for it and to minimize any potential problem areas. It is not our intention to judge the merits of the change; the wheels are obviously in motion already to proceed. For instance, most technical journals, including those in health physics and radiation research, have announced editorial policies to require SI units in all papers published after the current year. It should also be recognized that to some people in the profession the change appears as a trivial one and they can see no cause for alarm.

To clarify the situation the present project has addressed four areas:

1. The perception of people working in the field as to the extent and nature that a problem may exist.

2. Possible measures that can be taken to eliminate or remedy any identified problems.

3. Identification of the causes of lapses and other errors and estimation of any need to reinforce the change by retraining.

4. The nature of the change-over, whether mandatory or optional, sudden or prolonged, and the magnitude of any costs associated with it.

These topics will be covered in the following sections.

NATURE AND EXTENT OF THE PROBLEM

To evaluate the nature of the problem, its actual existence and the perception people in the profession have regarding its significance, three slightly different questionnaires were prepared and sent to representative groups.

The first questionnaire (A), illustrated in Fig. 1, was sent to members of the Health Physics Society. The mailing list was formulated by picking 500 labels from the Health Physics Society mailing list. These labels are organized by zip code; by picking a constant number of labels per page overrepresentation of any group or government agency can be avoided, except in as far as membership in the Society is disproportionately high so as to provide a bias. Similarly any geographical bias would presumably reflect a comparable distribution of health physicists. The questionnaires were mailed by Oak Ridge National Laboratory (M. Fair) and returned to Georgia Tech (Eichholz, Poston) for analysis. Five hundred U.S. and twelve foreign addresses were selected; 260 forms were returned for a response ratio of 51%.

The second questionnaire (B), illustrated in Fig. 2, was sent to a smaller group in nuclear medicine and radiology. One hundred and nine questionnaires were mailed: 40 returned for a response ratio of 37%.

The third questionaire (C), illustrated in Fig. 3 was addressed to manufacturers of radiation monitoring and detection equipment. Fifty nine forms were sent out or handed out at the Health Physics Society Annual Meeting. Twenty two were returned for a response ratio of 37%.

Fig. 1. Questionnaire A

1. What is your health physics specialty:

   ☐ medical physics ☐ plant surveillance ☐ instrumentation

   ☐ biology research ☐ other (specify)________________

2. How many years have you worked in this field?________________

3. What is your highest level of training: high school diploma ☐

   B.S. ☐ M.S. ☐ Ph.D. ☐ ☐ Other (specify)________________

4. Are you familiar with the new units? Yes ☐ No ☐

   If yes, where did you learn of the changeover?________________

5. Do you anticipate any problems with the new units?

   For yourself Yes ☐ No ☐

   For your staff Yes ☐ No ☐

	Yes	No
If yes, could this be overcome by a training course?	☐	☐
Do you currently have a training course?	☐	☐
By the use of instruments calibrated in the units?	☐	☐
By a long transition time?	☐	☐

   Other________________________________

6. Do you favor conversion to the new system? Yes ☐ No ☐

   If yes, abruptly by a given date? ☐

   Over a 3-year transitional period? ☐

   Over a period of 6 years? ☐

7. Which unit conversion would give you particular problems? None ☐

   rad → gray ☐ rem → sievert ☐ roentgen → C/kg ☐ Ci → Bq ☐

   All of the above ☐ If so, why?________________

8. Do you anticipate any significant costs to you associated with this conversion? Yes ☐ No ☐

Through needed retraining	" ☐	" ☐
Through needed recalibration of instruments	" ☐	" ☐
Through time lost in recalculations	" ☐	" ☐

   Others (specify) ________________________

   None ☐

9. Do you anticipate any hazards to you or your employees, your patients, etc. from the conversion? Yes ☐ No ☐

   If yes, specify ________________________

10. Any comments you wish to make:________________________

Fig. 2. Questionnaire B

1. What is your specialty:

☐ medical physics ☐ radiology ☐ nuclear medicine

☐ biology research ☐ other (specify)________________

2. How many years have you worked in this field?________________

3. What is your highest level of training: M.D. ☐ B.S. ☐ M.S. ☐

Ph.D. ☐ ☐ Other (specify)________________

4. Are you familiar with the new units? Yes ☐ No ☐

If yes, where did you learn of the proposed changeover?________________

5. Do you anticipate any problems with the new units?

For yourself Yes ☐ No ☐

For your staff Yes ☐ No ☐

	Yes	No
If yes, could this be overcome by a training course?	☐	☐
Do you currently have a training course?	☐	☐
By the use of instruments calibrated in the units?	☐	☐
By a long transition time?	☐	☐

Other________________

6. Do you favor conversion to the new system? Yes ☐ No ☐

If yes, abruptly by a given date? ☐

Over a 3-year transitional period? ☐

Over a period of 6 years? ☐

7. Which unit conversion would give you particular problems? None ☐

rad → gray ☐ rem → sievert ☐ roentgen → C/kg ☐ Ci → Bq ☐

All of the above ☐ If so, why?________________

8. Do you anticipate any significant costs to you associated with this conversion? Yes ☐ No ☐

Through needed retraining " ☐ " ☐

Through needed recalibration of instruments " ☐ " ☐

Through time lost in recalculations " ☐ " ☐

Others (specify)________________

9. Do you anticipate any hazards to you or your staff, your patients, etc. from the conversion?

To you or your staff Yes ☐ No ☐

To patients " ☐ " ☐

If yes, specify________________

10. Any comments you wish to make:________________

____

____

Fig. 3. Questionnaire C

1. What type of radiation sources do you supply:
   X-ray machines [ ]   accelerators [ ]   other sources [ ]
2. What type of monitoring instruments do you supply?
   Direct-reading ion chambers [ ]   Portable scintillation detectors [ ]
   Portable ion chambers [ ]   Portable GM counters [ ]
   Transmission ion chambers [ ]
   TLD readers [ ]   Others [ ]   Specify ______________
   R-meters [ ]   ______________
3. Are you familiar with the new units?
   [ ] Yes   [ ] No
4. Are you preparing any necessary changes in your equipment?
   [ ] Yes   [ ] No
5. Do you anticipate any problems with the conversion to yourself? [ ]
   to your customers? [ ]
   If so, why ______________
6. Do you favor conversion of existing instruments by issuing decals? [ ]
   by return of instruments to the plant? [ ]
   by issuing conversion calibration charts? [ ]
7. Do you anticipate any substantial cost (> 5% of purchase price) from such a conversion?
   to your company [ ]
   to the customer [ ]
8. Which unit conversion would give you particular problems?
   None [ ]   rad → gray [ ]   rem → sievert [ ]   roentgen → C/kg [ ]
9. If any future units have to be produced calibrated in the new units do you favor conversion
   abruptly, by an early date, e.g. 1981? [ ]
   over a 3-year transitional period? [ ]
   after a 6-year lead-in time? [ ]
10. Do you anticipate any significant costs to you associated with the introduction of the new units
   [ ] Yes   [ ] No
11. Do you anticipate any hazards to your employees or to your customers from this conversion
   [ ] Yes   [ ] No

   If yes, specify ______________
   ____
12. Any comments you wish to make: ______________
   ____

TABLE 1

Analysis of Questionnaires (A)

Question 1) - Health Physics Speciality:

		Number	Percent
a)	Medical Physics	53	20.4
b)	Plant Surveillance	61	23.5
c)	Instrumentation	20	7.7
d)	Biology Research	23	8.8
e)	Others (see below)	100	38.5
f)	All of the above	1	0.4
g)	No answer	2	0.8

Others (where specified): Education (25), Campus Health Physics (3), Clinical Research (6), Radiation Protection (5), Government Regulatory Agency (21), Environmental Surveillance (18).

Question 2) - Number of Years of Experience:

	Number of Years	Number	Percent
a)	1-5	38	14.6
b)	6-10	36	13.8
c)	11-15	32	12.3
d)	16 and more	149	57.3
e)	No answer	5	1.9

Question 3) - Highest Level of Training:

		Number	Percent
a)	High School Diploma	5	1.9
b)	B.S.	55	21.2
c)	M.S.	98	37.7
d)	Ph.D.	83	31.9
e)	Others (M.D., etc)	17	6.5
f)	No answer	2	0.8

Question 4) - Familiar With The New Units:

	Number	Percent
Yes	218	83.8
No	39	15.0
No answer	3	1.2

TABLE 1 (continued)

Question 5) - Do you anticipate any problems with the new units?:

		Number	Percent
a) For Yourself:	Yes	154	59.2
	No	105	40.4
	No answer	1	.04

b) For your staff: (see c)

	Number	Percent
Yes	182	70.0
No	56	21.5
No answer	22	8.5

c) If yes, could this be overcome by a training course?:

	Number	Percent
Yes	135	72.2
No	52	27.8

d) Do you currently have a training course?:

	Number	Percent
Yes	44	16.9
No	163	62.7
No answer	53	20.4

e) By the use of instruments calibrated in the new units?:

	Number	Percent	Percent of 182 yes
Yes	127	48.8	71.8
No	60	23.1	33.9
No answer	73	28.1	--

f) By a long transition time?:

	Number	Percent
Yes	138	53.1
No	52	20.0
No answer	70	26.9

TABLE 1 (continued)

Question 6) - Do you favor conversion to the new system?:

		Number	Percent
a)	Yes (see b)	84	32.3
	No	162	62.3
	No answer	14	5.4

b) If yes, abruptly by a given date?:

	Number	Percent of Total	Percent of Yes
Yes	26	10.0	30.9
No answer	234	90.0	--

c) Over a 3-year transitional period:

Yes	45	17.3	53.6
No answer	215	82.7	--

d) Over a period of 6 years:

Yes	35	13.5	41.7
No answer	225	86.5	--

Question 7) - Identify conversion causing problems:

	Number	Percent	No Answer	Percent of No Answer
None	86	33.1	174	100.0
rad → gray	34	13.1	-	19.5
rem → sievert	37	14.2	-	21.3
R → J/kg	41	15.8	-	23.6
Ci → Bq	41	15.8	-	23.6
All of the above	83	31.9	-	47.7

Question 8) - Do you anticipate any significant costs to you?:

a) Associated with this conversion:

	Number	Percent
Yes	155	59.6
No	64	24.6
No answer	41	15.8

b) Through needed retraining:

	Number	Percent
Yes	131	50.4
No	55	21.2
No answer	74	28.5

TABLE 1 (continued)

Question 8) (continued)

c) Through needed recalibration of instruments:

	Number	Percent
Yes	140	53.8
No	50	19.2
No answer	70	26.9

d) Through time lost in recalibrations:

Yes	144	55.4
No	45	17.3
No answer	71	27.3

e) None: 13 Answers and 247 No answers

Question 9) - Do you anticipate any hazards to you or your employees, your patients, etc. from the conversion?

Yes	98	37.7
No	140	53.8
No answer	22	8.5

Summary of questionnaire responses (A)

Number sent out: 512

Number returned: 260

Table 1 lists the responses by question and answers and the percentages in each group. Most of them are self-explanatory, but a few comments seem indicated.

Comments

Question 1. 21.5% of respondents were in medical physics and research, 38.5% were in "other" categories than listed, with a significant proportion in Government and Regulatory Agencies (8.1%), Universities and Teaching (9.6%) and Environmental Surveillance (6.9%).

Question 2. 57.3% of respondents had more than 15 years experience. This may imply that older recipients felt a greater responsibility to respond, or the age distribution reflects a rather serious deficiency in younger members in the Health Physics Society.

Question 3. Over 75% respondents had advanced degrees, supporting the previous comment.

Question 4 and 5. About 84% claim familiarity with the new units, but even so 59.2% anticipate problems in using them themselves and 70% expect problems for their staff. Of those 72.2% feel that a training course would be helpful, but only a few offer such a course at present.
Two thirds of those seeing problems feel that instrument recalibration would be helpful. 53.1% of respondents favor a long transition time; judging by added comments elsewhere, this probably includes some who dislike the change-over altogether.

Question 6. 62.3% of respondents dislike the new units! 5.4% had no opinion.
The subsidiary questions evidently drew responses from some of the noes, with no clearcut preference for a change-over period, except that delay seems preferred; however, the samples are small.

Question 7. 33.1% of respondents expected no problems. Of the rest several anticipated trouble with all of the conversions or more than one, with no particular conversion drawing any particular emphasis.

Question 8. 59.6% anticipated added costs from this conversion, in roughly equal proportion due to retraining, recalibration or lost time. The magnitude of these costs remains to be assessed.

Question 9. A surprising 38% of all respondents anticipated potential hazards from this conversion. If one takes the medically oriented respondents only, 27 or 51% perceived a hazard, 22 or 41% did not, and 4 had no opinion. Obviously this aspect needs to be further investigated.

Geographical Distribution

Table 2 lists the geographical distribution of respondents according to regions as shown in Fig. 4. On inspection it appears that each region seems to be reasonably represented though the West produced a higher response rate and the Midwest a lower one than the population distribution would indicate.

Summary

On the basis of the above analysis and attempts to establish additional correlations, the following conclusions could be drawn:

a) the conversion is disliked by the Health Physics profession;

b) an appreciable proportion of respondents see a tangible hazard associated with it; however, this view was not correlated with any particular professional group;

c) certain types of costs are anticipated that should be examined;

d) a definite need for training has been expressed, that will have to be met by the profession, the universities and/or relevant government agencies, probably jointly.

Questionnaires B and C

In view of the concerns expressed in the above poll, it seemed important to establish the views, particularly, of medical practitioners and the instrument industry. For this reason Questionnaire B was phrased to emphasize experience in medical areas. Table 3 lists the responses received.

Unfortunately the response rate was not very high, but presumably represents the more concerned portion of the group polled. This is borne out by the age distribution: 67.5% respondents had over 10 years experience. Nuclear Medicine and Medical Physics were represented by 35% each and 55% of respondents had M.D. degrees.

TABLE 2

Geographic Locations
(Also, see the map attached, Fig. 2)

Area Number	Number of Replies	Percent Response	Response Per 10^6 Population
1	79	30.4	1.22
2	46	17.7	1.27
3	24	9.2	0.59
4	23	8.8	1.00
5	63	24.2	1.75
6 (non US)	9	3.5	--
No answer	16	6.2	--

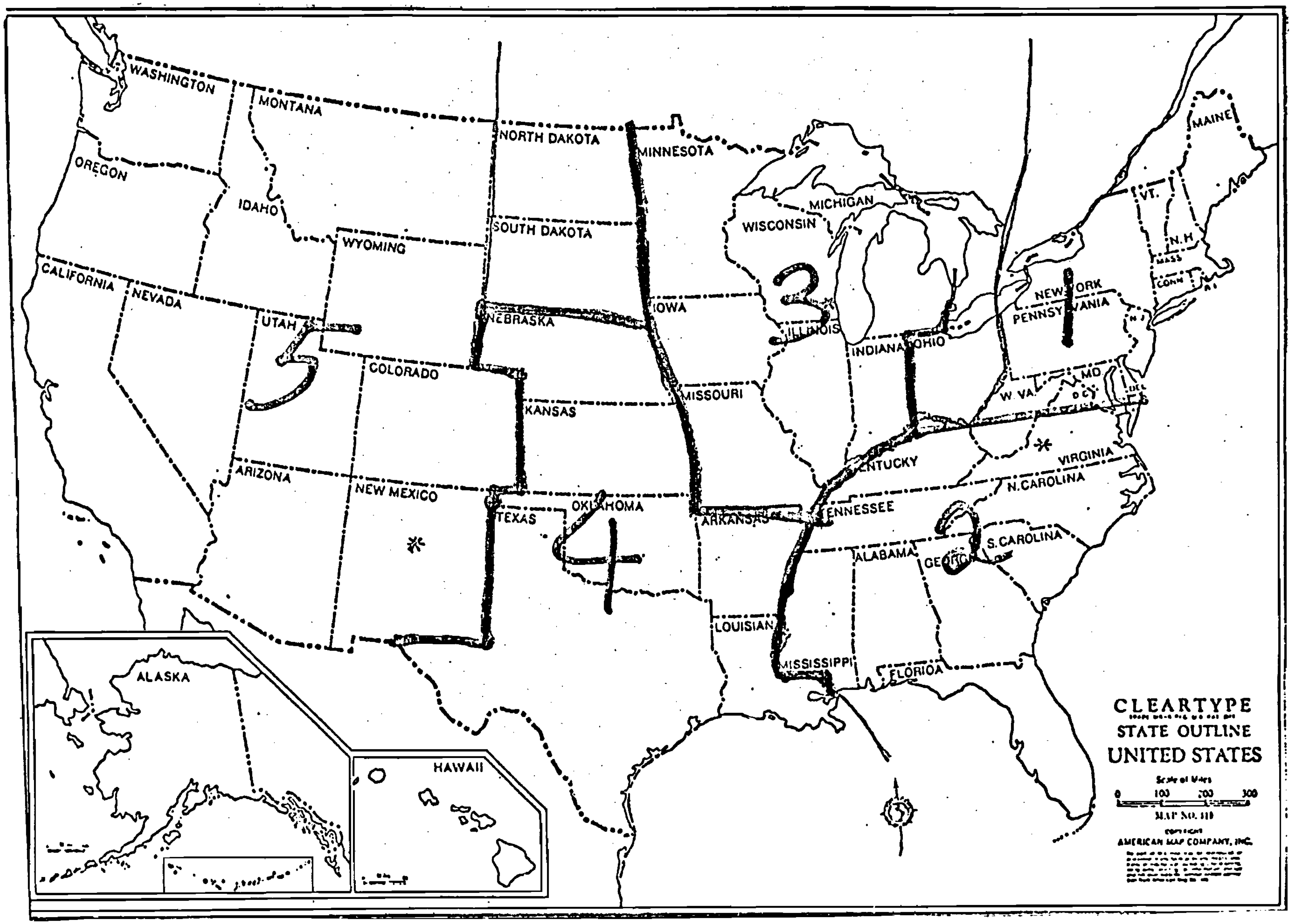


Fig. 4. Map of Assigned U.S. Regions

TABLE 3

Analysis of Responses-Questionnaire B

Total number sent: 100 + 9 Response 40

1) Speciality:

	No.	Percent
Medical Physics	14	35.0
Radiology	11	27.5
Nuclear Medicine	14	35.0
Others (Health Physics)	1	2.5

2) No. of years of experience:

No. of years	No.	Percent
A) 1-5	7	17.5
B) 6-10	6	15.0
C) 11-15	8	20.0
D) 16 and more	19	47.5

3) Highest level of training

	No.	Percent
A) M.D.	22	55.0
B) B.S.	3	7.5
C) M.S.	5	12.5
D) Ph.D.	8	20.0
E) Others	1	2.5
F) No answer	1	2.5

4) Familiar with the new units:

	No.	Percent
Yes	22	55.0
No	18	45.0

5) Do you anticipate any problems with the new unit?:

a) For yourself:

Yes	27	67.5
No	11	27.5
No answer	2	5.0

TABLE 3 (continued)

5) Do you anticipate any problems with the new units?:

b) For your staff

	No.	Percent
Yes	34	85.0
No	4	10.0
No answer	2	5.0

c) If yes, could this be overcome by a training course?:

Yes	27	67.5
No	7	17.5
No answer	6	15.0

d) Do you currently have a training course?:

Yes	3	7.5
No	32	80.0
No answer	5	12.5

e) By the use of instruments calibrated in the new units?:

Yes	19	47.5
No	12	30.0
No answer	9	22.5

f) By a long transition time?:

Yes	22	55.0
No	9	22.5
No answer	9	22.5

6) Do you favor conversion to the new system?:

a)

	No.	Percent
Yes	10	25.0
No	27	67.5
No answer	3	7.5

b) If yes, abruptly by a given date?:

	No.	Percent of Total	Percent of yes
Yes	3	7.5	30
No answer	37	92.5	--

c) Over a 3-year transitional period?:

Yes	6	15.0	60
No answer	34	85.0	--

TABLE 3 (continued)

6) Over a period of 6 years?:

	No.	Percent of total	Percent of Yes
Yes	3	7.5	30
No answer	37	92.5	--

7) Identify conversion causing problems:

	No.	Percent	Percent of yes
None	10	25.0	---
Rad → Gray	3	7.5	8.8
rem → sievers	2	5.0	5.9
R → C/kg	4	10.0	11.8
Ci → Bq	5	12.5	14.7
All of the above	18	45.0	52.9

8) Do you anticipate any significant cost to you?:

a) Associated with this conversion:

	No.	Percent
Yes	28	70.0
No	6	15.0
No answer	6	15.0

b) Through needed retraining:

	No.	Percent
Yes	28	70.0
No	4	10.0
No answer	8	20.0

c) Through needed recalibration of instruments:

	No.	Percent
Yes	27	67.5
No	4	10.0
No answer	9	22.5

d) Through time lost in recalibrations:

	No.	Percent
Yes	27	67.5
No	3	7.5
No answer	10	25.0

9) Do you anticipate any hazards to:

a) You or your staff:

	No.	Percent	Percent of MD
Yes	13	32.5	31.8
No	22	55.0	59.1
No answer	5	12.5	--

TABLE 3 (continued)

9) Do you anticipate any hazards to:

b) Patients?:

	No.	Percent	Percent of MD
Yes	24	60.0	50.0
No	14	35.0	40.9
No answer	2	5.0	--

10) Geographic locations (see the map)

Area No.	No. of replies	Percent response	Response per 10^6 population
1	11	27.5	0.17
2	5	12.5	0.14
3	6	15.0	0.15
4	2	5.0	0.22
5	7	17.5	0.19
not known	9	22.5	

Two-thirds of the group expected problems from the conversion for themselves, even more for their staff. The same proportion felt that a training course would help.

The large majority dislike the change; some of them expressed themselves strongly on the subject. Rather significantly, 60% of respondents, including half the M.D.'s foresee possible hazards to patients, and to a much lesser degree to their staff. This in many ways is at the core of the problem.

Unfortunately, it is not possible to pinpoint the nature of the hazard precisely. The general consensus, established mainly through informal discussions, seems to be that the changes from röntgen to the rather inconvenient coul/kg and from rads to grays are most likely to cause trouble. This problem is assumed to arise from errors in reading a dose indication assumed to be in rads when it is in grays, from failure to apply the conversion ratio of 100 in the right direction and from the use of outmoded calibrations or dials.

As the responses to Question 8 in Questionnaire B show, two-thirds of respondents expected that instruments will have to be recalibrated and that some real costs in time and money would be associated with that. To explore this matter further, Questionnaire C was sent out to the manufactures.

Responses to Questionnaire C are listed in Table 4. Most of the manufacturers responding are aware of the new units, but only a few are preparing any changes. In discussion with representatives, there appeared to be a consensus that new instruments could easily be supplied calibrated in grays, whether the instruments are digital or dial type. Use of the centigray in lieu of the rad is advocated by some, but we feel that introduction of yet another unit will only compound the confusion.

The manufacturers do anticipate substantial costs, in excess of five percent of the purchase price, to retrofit equipment by changing scales on dial instruments or conversion factors in digital ones. They favor, but only by a narrow margin, an early and fairly abrupt transition date.

Summary

Both the medical group and the manufacturers see significant costs associated with the change in units as well as some potential hazards, especially to patients, arising mainly from human error or miscalibration of instruments. In discussions it was usually felt that this was not an insuperable problem, but could be solved by training, procurement of new instruments, and a willingness to use the new units as they are introduced.

TABLE 4

Analysis of responses - Questionnaire (C)

Total number sent: 59 Response 22

		No.	Percent
1)	Type of radiation source:		
	X-ray machine	0	0
	Accelerators	0	0
	Other sources	11	50
	No answer	11	50
2)	Type of monitoring instruments:		
	a) Direct-reading ion chambers	6	27
	b) Portable ion chambers	6	27
	c) TLD readers	5	23
	d) R-meters	2	9
	e) Portable scintillation detectors	8	36
	f) Portable GM counters	8	36
	g) Transmission ion chambers	0	0
	h) Others*	9	41

*Others include: Remote area monitors, digital meters, personal dosimeter

3)	Familiar with the new unit:		
	Yes	18	82
	No	4	18
4)	Are you preparing any necessary changes in your equipment:		
	Yes	4	18
	No	16	73
	No answer	2	9

TABLE 4 (continued)

5) Do you anticipate any problems with the conversion to:

a) Yourself

	No.	Percent
Yes	9	44
No	4	18
No answer	9	41

b) Your customer:

	No.	Percent
Yes	14	64
No	2	36
No answer	6	

6) Do you favor conversion of existing instrument by issuing decals?:

a)

	No.	Percent
Yes	4	18
No	5	82
No answer	13	

b) By return of instruments to the plant::

	No.	Percent
Yes	6	27
No	3	73
No answer	13	

c) By issuing conversion calibration charts?:

	No.	Percent
Yes	3	14
No	1	86
No answer	18	

7) Do you anticipate any substantial cost from such a conversion? (>5% of purchase price)

a) To your company:

	No.	Percent
Yes	12	55
No	3	45
No answer	7	

b) To the customer:

	No.	Percent
Yes	15	68
No	3	32
No answer	4	

TABLE 4 (continued)

8) Which unit conversion would give you particular problems?:

		No.	Percent
a)	None	7	32
	No answer	15	68
b)	Rad → gray	4	18
	No answer	18	82
c)	Rem → sievert	3	14
	No answer	19	86
d)	Roentgen → C/kg	7	32
	No answer	15	68

9) If any future units have to be produced calibrated in the new units, do you favor conversion?:

Abruptly, by an early date, e.g. 1981?	7	32
Over a 3-year transitional period?	5	23
After a 6-year lead-in time?	8	36
No answer	2	9

10) Do you anticipate any significant costs to you associated with the introduction of the new units?

Yes	11	50
No	10	45
No answer	1	5

11) Do you anticipate any hazard to your employees or to your customers from this conversion?

Yes	12	55
No	9	41
No answer	1	4

IMPLEMENTATION

1. Transition Period

The British report[4] advocates a transition period during which, in documents, at first the new units would follow the old ones in parentheses, and later the sequence be reversed. This is the procedure followed by many U.S. technical journals. It also suggests retention of the old units in official documents until 1982, but not beyond 1985. In discussions with instrument manufacturers and users during the present study, it was generally felt that a rapid change was less expensive and less likely to lead to confusion than a prolonged period during which both sets of units were employed side by side. A long transition period seemed to be advocated by outright opponents of the conversion, in the hope that long deferment would lead to ultimate abandonment of the proposal.

Despite the many objectives to the change voiced in the questionnaire, this change must be considered inevitable. Under the circumstances it is recommended to set an early date for implementation, such as January 1, 1982, with a dual reference to both units in all official documents during the intervening period. Such an early date avoids an excessive period when industrial use is out of step with the technical literature, both U.S. and worldwide. Experience in other countries on metric conversions has shown that one year is sufficient to alert the concerned group to the impending change-over, while a longer transition period merely prolongs the agony and public uncertainty. In most cases predictions for the time needed for effective conversion have been proved overpessimistic. For example, the change from gallons to liters in selling gasoline in Canada has caused little inconvenience to the public. Even the British change to metric currency, removing the time-honored pound-shilling-pence (20-12-1) scheme, in retrospect was done correctly by abrupt implementation.

A longer period may be required to amend old legislation or regulations, to minimize a great deal of unnecessary document changes. The British report[4] recommends "that any legislation enacted during the transition period should be drafted in such a way as to allow for the later demise of the old special units."

Some difficulties will arise in U.S. regulations phrased in röntgens or curies, where direct numerical conversion is inconvenient and rounding off, up or down, may lead to significant changes. Examples of these would be packaging regulations for radioactive materials (10CFR71), exempt quantities (10CFR30) or surface contamination criteria (10CFR140). Under protective regulations for x-ray equipment, abandonment of the exposure concept, and the röntgen with it, will require some policy decisions regarding optimum implementation of the change-over.

Numerical conversion will be of three types:

a) Those where present regulations incorporate numerical examples, which can be converted to metric units directly with no loss in significance or impact;

b) Those where present numbers were initially order-of-magnitude quantities, and it seems reasonable to round them up or down with little loss in general applicability; and

c) Those where rounding up or down on conversion represents a significant change, e.g. more than 15%, in resultant dose or exposure limits.

It is the latter two classes that will have to be evaluated paragraph by paragraph to estimate the regulatory consequences or the magnitude of the dose commitment resulting from metric conversion or rounding off of figures. This evaluation is in progress. Appendix A shows some examples of all three types of conversion categories.

While such an impact evaluation is proceeding, this editorial revision of regulations may provide an opportunity, as Goldfinch[5] has pointed out, through the introduction of becquerels to rederive the permitted levels of contamination from first principles and in the process to eliminate some of the unreal pessimism ("conservatism") built in for isotopes of very low radiotoxicity.

2. Training

Most respondents have commented favorably on the use of training to minimize errors arising from the proposed conversion. There are two aspects to this. First it is important to indoctrinate current students and trainees to think and work in the new units right away. This means all current training programs should be conducted primarily in the new units, so that new entries into the profession will not be confronted with any need to re-adjust their thinking. Second, for those already engaged in radiation work, brief refresher courses will be needed to introduce, and familiarize them with, the new units through practical training programs and workshops.

Such programs would have to be directed primarily at hospital and laboratory technicians, health physics personnel at all levels, and radiological and nuclear medicine clinical personnel. The programs could be conducted by state medical associations, national laboratories and associated organizations, such as ORAU and AAU, and by health physics (or similar) departments at universities. One- or two-day intensive programs should be adequate, conducted as far as possible in a local environment.

Education and training must be a major facet of any change-over to SI units. We believe that each installation should conduct its own training program. Also, all national meetings of technical societies during the next two years should provide for refresher sessions dealing with SI units.

The experience at ORNL should be typical of any installation where health physics activities have been carried on for a number of years. It was found that three one-hour sessions, (meeting on Monday, Wednesday, Friday) were sufficient to review the old units and introduce the new units. A one-hour review session after allowing a two-month soaking-in period was extremely valuable. This program was presented to 40 health physicists and health physics technicians. Each group consisted of only 10 people to assure that health physics field coverage was kept adequate. It was concluded that four hours of formal training was sufficient for these people but it was clear that practice is required to gain facility in converting units.

Figure 5 was prepared for training purposes and also for field office use. It was found that this sheet provided ease of conversion and even better it provided confidence that a conversion could be done correctly.

The section labeled OLD UNITS to NEW UNITS is the section that receives the greatest amount of use since this is the direction in which we are going. However, it is useful to have the inverse available; therefore, the section NEW UNITS to OLD UNITS has been included. Three scales have been included strictly for "checking" purposes. It is not intended that these scales be used to make the conversion but rather to be used as a check, mainly for order of magnitude, after the conversion has been made. Also included are some prefixes with their proper symbols and numerical values.

Theoretically all that one really needs are the four conversion factors: 1 Ci = 3.7×10^{10} Bq, 1 rem = 0.01 Sv, 1 rad = 0.01 Gy, and 1 R = 2.58×10^{-4} C/kg; however, in actual practice it was found that a sheet such as the one provided here is invaluable for ease of conversion and assuring a minimum of errors. After a short period of use one gains facility in making conversion and one could go through the various parts of 10 CFR and easily make the conversions required using this sheet.

If the change-over date, such as January 1, 1982, is accepted and if at that time all schools quit teaching the old units, then the complete transition to the SI units will be achieved in a few years. This was done in the medical field when they changed from the apothecary system to the metric system, i.e., a date was set at which time the apothecary system was no longer taught at medical schools.

ORNL had set January 1, 1980, as the change-over date to SI units. However, the Department of Energy had not established a position on adoption of SI units in applied health physics programs and the old units have been retained until further notice. The Department of Energy now have proposed that a multi-year change-over program be used to provide for a smooth transition, which would fit in very closely with this group's recommended change-over date of January 1, 1982.

It may be desirable to incorporate attendance at a retraining course of this type in the requirements for renewal of a radioisotope license or a comparable radiological qualification.

ORNL-DWG 79-18817

OLD UNITS to NEW UNITS

rem → sievert (Sv) and rad → gray (Gy)

1 rem = .01 Sv = 1 centi Sv = 10 milli Sv = 10^4 micro Sv

10 rem = .1 Sv = 10 centi Sv = 100 milli Sv = 10^5 micro Sv

100 rem = 1 Sv = 100 centi Sv = 1000 milli Sv = 10^6 micro Sv

1 millirem = .01 milli Sv = 10 micro Sv

10 millirem = .1 milli Sv = 100 micro Sv

100 millirem = 1 milli Sv = 1000 micro Sv

1 microrem = .01 micro Sv = 10 nano Sv = 10^{-8} Sv

roentgen (R) → coulomb (C) per kilogram (kg)

1 R = 2.58×10^{-4} C/kg = .258 milli C/kg = 258 micro C/kg ≈ 260 $\frac{\mu C}{kg}$

10 R = 2.58×10^{-3} C/kg = 2.58 milli C/kg = 2580 micro C/kg

100 R = 2.58×10^{-2} C/kg = 25.8 milli C/kg

1 milli R = 2.58×10^{-7} C/kg = 2.58×10^{-4} milli C/kg = .258 micro C/kg

10 milli R = 2.58×10^{-6} C/kg = 2.58×10^{-3} milli C/kg = 2.58 micro C/kg

100 milli R = 2.58×10^{-5} C/kg = 2.58×10^{-2} milli C/kg = 25.8 micro C/kg

curie (Ci) → becquerel (Bq)

1 curie = 3.7×10^{10} dis/sec = 3.7×10^{10} Bq = .037 tera Bq

10 curie = 3.7×10^{11} dis/sec = 3.7×10^{11} Bq = .37 tera Bq

100 curie = 3.7×10^{12} dis/sec = 3.7×10^{12} Bq = 3.7 tera Bq

1000 curie = 3.7×10^{13} dis/sec = 3.7×10^{13} Bq = 37 tera Bq

1 milli Ci = 3.7×10^7 Bq = 37 mega Bq

1 micro Ci = 3.7×10^4 Bq = .037 mega Bq = 37 kilo Bq

1 nano Ci = 37 Bq

1 pico Ci = .037 Bq = 37 milli Bq

100 milli Ci = 3.7 giga Bq

100 micro Ci = 3.7 mega Bq

NEW UNITS to OLD UNITS

1 gray = 1 Gy = 1 joule/kilogram = 1 J/kg = 100 rad

1 milli Gy = 100 millirad = .1 rad

1 micro Gy = .1 millirad = 10^{-4} rad

ALSO: sievert (Sv) → rem

1 C/kg = 3876R

1 milli C/kg = 3.876 R

1 micro C/kg = 3.876×10^{-3} R = 3.876 milli R

1 nano C/kg = 3.876×10^{-6} R = 3.876 micro R

1 Bq = 1 dis/sec = 2.7×10^{-11} Ci = 27 pico Ci

1 kilo Bq = 27 nano Ci

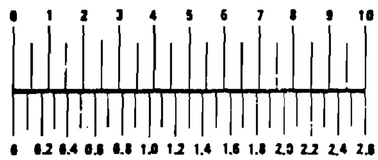
1 mega Bq = 27 micro Ci

1 giga Bq = 27 milli Ci

1 tera Bq = 27 Ci

1 peta Bq = 27,000 Ci

Roentgen (R)



$\frac{\text{milli coulomb}}{\text{kilogram}}$ $\frac{mC}{kg}$

3 kilo (k)	–3 milli (m)
6 mega (M)	–6 micro (μ)
9 giga (G)	–9 nano (n)
12 tera (T)	–12 pico (p)
15 peta (P)	–15 femto (f)
18 exa (E)	–18 atto (a)

The numbers indicate powers of 10.
Example: exa – 10^{18} nano – 10^{-9}

1 attoCi	1 femtoCi	1 picoCi	1 nanoCi	1 microCi	1 milliCi	1 Ci	10 Ci	100 Ci	1000 Ci	1 megaCi	1 gigaCi
37 nanoBq	37 microBq	37 milliBq	37 Bq	37 kiloBq	37 megaBq	37 gigaBq .037 teraBq	.37 teraBq	3.7 teraBq	37 teraBq	37 petaBq	37 exaBq

rad or rem

0	1	2	3	4	5	6	7	8	9	10
0	10	20	30	40	50	60	70	80	90	100

milligray or millisievert

Figure 5. Conversion Tables

The cost of retraining is rather difficult to assess, but would probably be of the order of $10 to $50 per trainee, not counting the time lost by attending the program. The latter cost might reasonably be borne by the employer; the cost of conducting the course itself may have to be provided from state or federal funds. However, this will depend on the perception of Congress of the urgency and potential impact of the conversion. For instance, in the interest of rapid standardization the Department of Defense might support training courses for Defense and Defense-related personnel.

3. Instrument Calibration

New instruments can easily be supplied calibrated in either old or new units and no additional costs are anticipated to either users or suppliers, beyond that of updating instruction manuals and sales literature, which is passed on to the consumer anyhow. With regard to recalibration of old units or changes in dial scales, some criteria as to unit cost, age, and potential for harm if left unchanged will have to be developed to justify the cost. Part of that cost may have to be supported by the Government through direct credits, tax-exemption or deductibility. No estimate is available at this time on the number of instruments potentially involved; this will, of course, depend on the criteria mentioned.

CAUSES OF LAPSES OR ERRORS

Most individuals that expressed concern at the change in units did so because of a perceived hazard arising mainly from inadvertent over-exposure of patients or radiation workers due to a momentary confusion between doses expressed in grays and the familiar notion of expressing them in rads. The difference of two orders of magnitude, obviously, could have serious consequences. The question is, how probable such an error may be.

It is generally assumed that even a conscientious and well-trained person may unconsciously revert to earlier training concepts under the effects of fatigue, nervous strain, pressure or frequent disturbances. Attempts have been made to find data on the probability of such transfer actions in a clinical or emergency setting; however, no such indications could be found either through the Human Factors Reports Index at Sandia Laboratories (Dr. L. V. Rigby) or through library surveys at Georgia Tech. Table 5 lists some of the references scanned.

All of the articles listed under the headings of Sources/Psychology were scanned, with the exception of the HumRRO Technical Reports, of which the abstracts alone were read. It would seem, on the basis of what is generally known of transfer, that negative transfer effects would be possible if the task in question is verbally mediated in any sense.

However, the literature search failed to support the presumed existence of studies of transfer effects in applied fields. An explanation of this phenomenon is supplied by McCormick[6]: "Although such theories have an intuitive appeal, it should be added that there is no operational basis for measuring the degree of similarity between different stimuli or responses, or for estimating "how much" transfer would occur in any given situation. At the present time we probably need to acknowledge the bald fact that there is no generally confirmed theory related to transfer of learning that lends itself to practical application."

It has been suggested that specific experimental research is required if negative transfer effects are to be accurately measured.

Despite this inability to come up with specific values for the probability of occurrence for such errors that may lead to serious over-exposure, one is clearly not justified to ignore this as a potential hazard in the face of the wide-spread impression that this is, in fact, a significant source of trouble. Reversion to previous training and reactions under stress are a common experience and it should be possible to find relevant data in the records of training experience for pilots and astronauts and other well-documented groups.

TABLE 5

List of References Reviewed

SOURCES

Psychology

Bull. of Psychonomic Science, Vol. 8 (3), 167
Journal of Experimental Psychology, Vol. 103, (1), 54
Dissertation Abstracts Int'l, 1973, (Sept.) Vol. 34A, 1140
Journal of Experimental Psychology, Learning and Memory
Vol. 104 (1) (3), 326
Journal of General Psychology, Vol. 91 (2), 295
Journal of Motor Behavior, Vol. 8 (1), 1
Dissertation Abstracts Int'l, 1972, (Dec.) Vol. 33A, 2774
Dissertation Abstracts Int'l, 1972, (Sept.) Vol. 33B, 1302
Journal of Experimental Psychology, Vol. 95 (2), 375
Journal of Experimental Psychology, Vol. 99 (3), 381
Annual Review of Psychology, Vol. 20, 301
Psychological Reports, Vol. 26 (2), 475
Psychonomic Science, Vol. 20 (2), 71
Proceedings of the APA 1970, Vol. 5 (pt. 1), 73
HumRRO Technical Report, 1970 (June), No. 70-7, 30
HumRRO Technical Report, 1970 (June), No. 70-10
Ellis, A.C., Bennett, T.L., Daniel, T.C. Rickert, E.J., Psychology of Learning and Memory, Monterey, CA., Brooks/Cole, 1979

Human Factors

*Human Factors - all volumes in Ga. Tech Library
*Ergonomics - all volumes in Ga. Tech Library
*Applied Ergonomics - all volumes in Ga. Tech Library
*Int'l Journal of Man-Machine Systems - all volumes in Ga. Tech Library
McCormick, E.J., Human Factors in Engineering & Design New York: McGraw-Hill, 1976
Van Cott, H.P., and Kinkade, R.G., (Eds.). Human Engineering Guide to Equipment Design. New York: McGraw-Hill, 1972

Government Abstracts

Scientific and Technical Aerospace Reports
Government Reports Annual Index

*These journals were checked for relevant articles on a volume-by-volume basis, in spite of their being listed in the Social Science Citation Index, which served as the foundation of the literature search.

COST ESTIMATES

Any major change in technical usage has certain costs associated with it. These may be classified as

<u>Tangible costs</u>: e.g. new instruments, recalibration, retraining of personnel, document conversion, legislative changes, publication costs

and

<u>Intangible costs</u>: e.g. risk of overexposure, risk of mispreparation of radiopharmaceuticals, effects of delay, costs of not making the change in terms of international trade, market losses, international cooperation.

These costs can be appreciable for larger organizations, such as the Defense Department, National Institutes of Health or TVA, where several thousand people may require retraining and hundreds of instruments may have to be recalibrated.

Typical cost estimates received included a cost of $80-100,000 for retraining 4000 radiation workers through a half-day course; $60,000 to retrain 1000 workers with a public utility.

The cost of a training film may be of the order of $20-30,000.

Not all instruments need to be converted, but a TVA estimate was for $150 per dial scale change, required for possibly 150-180 instruments. Other estimates range around $30-50 per instrument depending on the type of instrument, the change required and the numbers involved.

Changes in computer codes and record keeping may cost up to $20,000 per organization. Re-issue of radiation safety guides has been estimated to require one man-month of work at NIH, with an overall cost of about $10,000. Revision of all radiation related regulations and guides issued by U.S. NRC, EPA, DOE, DOT, HEW and other agencies will, obviously, require a major effort and may cost in the neighborhood of $1M, though much of it will be absorbed in normal duties.

With regard to the intangible costs these are much more difficult to estimate. It has been suggested that there is a normal incidence of exposure errors in radiation therapy of the order of 4-5% of all treatments. On that scale the SI conversion may contribute an insignificant increment of excess errors.

It is presupposed here that the unit conversion will, in fact, take place so that consideration of the cost of not converting does not arise. However, it obviously has been considered seriously by Congress and those advocating the change.

It may be added that the general experience in conversion to metric units elsewhere has usually shown that the process was considerably less painful than expected.

BENEFITS

In view of the wide-spread reluctance of the medical and health physics profession to change to SI radiation units, as indicated by the questionnaires, the benefits accruing from yet another change in radiation units may seem paltry and intangible indeed. However, there are some valid benefits that justify conversion and it is important to present them.

These benefits are:

1. Coordination of the United States with international practice by the use of common, world-wide units. This concept, which underlies the whole metric conversion, is particularly important in the radiation field where international cooperation and scientific understanding are of crucial importance.

2. Consistency of units. The aim of the SI system is to provide for ready convertibility of units and a self-consistent use of dimensions. Though this is usually less significant in radiation applications in the medical and radiation-protection fields than in industrial use, it still will be helpful in many computations.

3. Clearer distinction between radiation quantities. The use of the gray and sievert and their numerical separation from any exposure unit, which were numerically similar for x- and gamma-rays for largely historical reasons, will emphasize once and for all the essential differences between the concepts of dose, dose equivalent and exposure. This should be helpful in education and training where in the past the concepts tended to be blurred despite the effort of various national and international commissions to clarify these concepts.

It is to be hoped that those commissions will refrain from introducing further changes in definitions or concepts for a considerable period after these traumatic conversions have been accepted by the professions.

SUMMARY

By questionnaires to health physicists, selected members of the medical profession and nuclear instrument manufacturers it has been demonstrated that there is wide-spread reluctance to any change in the common radiation units to SI equivalents. There is also a strong suspicion that such a change in units may lead to hazardous situations to patients and clinical personnel due to unfamiliarity with the new units or to memory lapses. The magnitude of this hazard, though it is widely perceived, seems to be difficult to quantify. Accepting the inevitability of the conversion, additional education and retraining appear to be the most effective means of minimizing these hazards. The cost of instrument conversion is insignificant for new units but may be substantial for existing installations. There is also a significant effort involved in recasting existing laws and regulations that may be affected. The man-year effort involved is hard to quantify; most of it may involve legal reviews, and administrative controls. However, a minimum of two man-years of NRC staff time seems a reasonable estimate.

In summary, assuming legal authorization for conversion to SI units in all radiation activities subject to licensing by U.S. government agencies it is recommended:

1) The change-over to SI unit should occur at an early date, such as January 1, 1982, to minimize the period of uncertainty and to install new units calibrated in the new units as soon as possible.

2) In the intervening period all official documents should show both sets of units, with a gradual de-emphasis of the old ones.

3) Training courses to familiarize all affected personnel should be planned under the auspices of technical societies, medical associations and state organizations, with such Federal support as may be appropriate.

Federal support may be in the form of developing training aids, supplying instructors or facilities, as well as direct financial support where that seems appropriate.

4) All federal regulations and guidelines should be examined to determine the need for re-wording or redefining applicable regulations and to determine the potential safety impact of rounding off converted quantities in the new units.

5) Steps should be taken to ensure a uniform approach among all governmental agencies that may be involved in this conversion, as well as any standard-setting organizations.

REFERENCES

1. National Bureau of Standards. The International System of Units NBS Spec. Publ. 330, 3rd. ed, 1977.

2. U.S. Dept. of Commerce. Preferred Metric Units for General Use by the Federal Government. Circular LC 1098, National Bureau of Standards, Washington, D.C., 1978.

3. J. E. Burns. The New SI Units - Problems of Conversion in "Advances in Radiation Protection Monitoring," IAEA, Vienna, 1974.

4. British Committee on Radiation Units and Measurements. Recommendations on the Introduction of the New SI Units for use with Radioactivity and Ionizing Radiations. National Physical Laboratory, Teddington, Mddx., 1978.

5. E. P. Goldfinch. Development of radiological safety rules within the CEGB. in "Radiation Protection in Nuclear Power Plants and the Fuel Cycle." Brit. Nuclear Energy Soc., London, 1978.

6. E. J. McCormick. "Human Factors in Engineering and Design." 4th ed. McGraw-Hill Book Co., New York, 1976.

7. International Commission on Radiological Protection. Publication 26, 1977.

LIBRARY DOES NOT HAVE

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APPENDIX A

Examples of Unit Conversion Effects in Federal Regulations (Title 10).

A. Type I cases: Direct conversion to metric and SI units without significant rounding off.
No regulatory problems involved.

Chapter I—Nuclear Regulatory Commission **§ 51.20**

[Normalized to model LWR annual fuel requirement (WASH-1248) or reference reactor year (NUREG-0116)]—Continued

Natural resource use	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1,000 MWe LWR	Converted Units
Other gases:			
F^-	.67	Principally from UF_6 production, enrichment, and reprocessing. Concentration within range of state standards—below level that has effects on human health.	
HCl	.014		
Liquids:			
SO_4^{--}	9.9	From enrichment, fuel fabrication, and reprocessing steps. Components that constitute a potential for adverse environmental effect are present in dilute concentrations and receive additional dilution by receiving bodies of water to levels below permissible standards. The constituents that require dilution and the flow of dilution water are:	
NO_3^-	25.8		
Fluoride	12.9		
Ca^{++}	5.4		
Cl^-	8.5		
Na^+	12.1		
NH_3	10.0		
Fe	.4	NH_3—600 ft³/s. NO_3—20 ft³/s. Fluoride—70 ft³/s.	17 m³/s 0.57m³/s 1.98m³/s
Tailings solutions (thousands of MT)	240	From mills only—no significant effluents to environment.	
Solids	91,000	Principally from mills—no significant effluents to environment.	
Effluents—Radiological (curies):			
Gases (including entrainment):[a]			
Rn-222	74.5	Principally from milling operations and excludes contributions from mining	2.76 TBq
Ra-226	.02		0.74 GBq
Th-230	.02		0.74 GBq
Uranium	.034		1.26 GBq
Tritium (thousands)	18.1		670 TBq
C-14	24		888 GBq
Kr-85 (thousands)	400		14.8 PBq
Ru-106	.14	Principally from fuel reprocessing plants.	5.18 GBq
I-129	1.3		48.1 GBq
I-131	.83		30.7 GBq
Fission products and transuranics	.203		7.51 GBq
Liquids:[a]			
Uranium and daughters	2.1	Principally from milling—included in tailings liquor and returned to ground—no effluents; therefore, no effect on environment.	77.7 GBq
Ra-226	.0034	From UF_6 production.	0.126 GBq
Th-230	.0015		0.056 GBq
Th-234	.01	From fuel fabrication plants—concentration 10 pct of 10 CFR 20 for total processing 26 annual fuel requirements for model LWR.	0.37 GBq
Fission and activation products	5.9×10^{-6}		0.22 MBq
Solids (buried on site):			
Other than high level (shallow)	11,300	9,100 Ci comes from low-level reactor wastes and 1,500 Ci comes from reactor decontamination and decommissioning—buried at land burial facilities. 600 Ci comes from mills—included in tailings returned to ground ~60 Ci comes from conversion and spent fuel storage. No significant effluent to the environment.	0.42 PBq,etc.
TRU and HLW (deep)	1.1×10^7	Buried at Federal repository.	0.407 EBq
Effluents—Thermal (billions of British Thermal units).	3.462	<4 pct of model 1,000 MWe LWR.	3.65 PJ
Transportation (person-rem): Exposure of workers and general public.	2.5		0.02 × 5 man-Sv
Occupational exposure (person-rem)	22.6	From reprocessing and waste management.	0.226 man-Sv

Title 10—Energy

	Converted Units precise	Converted Units rounded
1. *Heat*—Direct sunlight at an ambient temperature of 130° F. in still air.	54.44°C	55°C
2. *Cold*—An ambient temperature of −40° F. in still air and .025 shade.	-40°C	-40°C

3. *Pressure*—Atmospheric pressure of 0.5 times standard atmospheric pressure.

4. *Vibration*—Vibration normally incident to transport.

5. *Water Spray*—A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period of 30 minutes.

6. *Free Drop*—Between 1½ and 2½ hours after the conclusion of the water spray test, a free drop through the distance specified below onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

FREE FALL DISTANCE

Package weight (pounds)	*Distance (feet)*	Converted Units precise	Converted Units rounded
Less than 10,000	4	<4536 kg; 1.22 m	<5000 kg at 1.20 m
10,000 to 20,000	3	0.914 m	5000-10,000 kg at 1.00 m
20,000 to 30,000	2	0.61	10,000-15,000 kg at 60 cm
More than 30,000	1	0.305 m	<15,000 kg at 30 cm

7. *Corner Drop*—A free drop onto each corner of the package in succession, or in the case of a cylindrical package onto each quarter of each rim, from a height of 1 foot onto a flat essentially unyielding horizontal surface. This test applies only to packages which are constructed primarily of wood or fiberboard, and do not exceed 110 pounds gross weight, and to all Fissile Class II packagings.

Converted units: 30 cm.; 50 kg wt

8. *Penetration*—Impact of the hemispherical end of a vertical steel cylinder 1¼ inches in diameter and weighing 13 pounds, dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture. The long axis of the cylinder shall be perpendicular to the package surface.

precise	rounded
31.75 mm	32 mm diam.
5.9 kg	5.9 kg
1.016 m	1.0 m

9. *Compression*—For packages not exceeding 10,000 pounds in weight, a compressive load equal to either 5 times the weight of the package or 2 pounds per square inch multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally be transported.

precise	rounded
	5000 kg
1406 kg/m²	1500 kg/m²

[31 FR 9941, July 22, 1966, as amended at 33 FR 17623, Nov. 26, 1968]

B. Type II cases: Rewriting of paragraphs in new units.

Example: Definition of units, needs rewording.

8783, Mar. 3, 1975; 40 FR 42558, Sept. 15, 1975]

§ 20.4 Units of radiation dose.

(a) "Dose," as used in this part, is the quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. When the regulations in this part specify a dose during a period of time, the dose means the total quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body during such period of time. Several different units of dose are in current use. Definitions of units as used in this part are set forth in paragraphs (b) and (c) of this section.

(b) The rad, as used in this part, is a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue. (One millirad (mrad)=0.001 rad.)

(c) The rem, as used in this part, is a measure of the dose of any ionizing radiation to body tissues in terms of its estimated biological effect relative to a dose of one roentgen (r) of X-rays. (One millirem (mrem)=0.001 rem.) The relation of the rem to other dose units depends upon the biological effect under consideration and upon the conditions of irradiation. For the purpose of the regulations in this part, any of the following is considered to be equivalent to a dose of one rem:

(1) A dose of 1 r due to X– or gamma radiation;

(2) A dose of 1 rad due to X–, gamma, or beta radiation;

(3) A dose of 0.1 rad due to neutrons or high energy protons;

(4) A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye; If it is more convenient to measure the neutron flux, or equivalent, than to determine the neutron dose in rads, as provided in paragraph (c)(3) of this section, one rem of neutron radiation may, for purposes of the regulations in this part, be assumed to be equivalent to 14 million neutrons per square centimeter incident upon the body; or, if there exists sufficient information to estimate with reasonable accuracy the approximate distribution in energy of the neutrons, the incident number of neutrons per square centimeter equivalent to one rem may be estimated from the following table:

NEUTRON FLUX DOSE EQUIVALENTS

Neutron energy (Mev)	Number of neutrons per square centimeter equivalent to a dose of 1 rem (neutrons/cm^2)	Average flux to deliver 100 millirem in 40 hours (neutrons/cm^2 per sec.)
Thermal	970×10^6	670
0.0001	720×10^6	500
0.005	820×10^6	570
0.02	400×10^6	280
0.1	120×10^6	80
0.5	43×10^6	30
1.0	26×10^6	18
2.5	29×10^6	20
5.0	26×10^6	18
7.5	24×10^6	17
10	24×10^6	17
10 to 30	14×10^6	10

(d) For determining exposures to X or gamma rays up to 3 Mev, the dose limits specified in §§ 20.101 to 20.104, inclusive, may be assumed to be equivalent to the "air dose". For the purpose of this part "air dose" means that the dose is measured by a properly calibrated appropriate instrument in air at or near the body surface in the region of highest dosage rate.

§ 20.5 Units of radioactivity.

(a) Radioactivity is commonly, and for purposes of the regulations in this part shall be, measured in terms of disintegrations per unit time or in curies. One curie=3.7×10^{10} disintegrations per second (dps)=2.2×10^{12} disintegrations per minute (dpm). Commonly used submultiples of the curie are the millicurie and the microcurie:

(1) One millicurie (mCi) [1]=0.001 curie (Ci) [1]=3.7×10^7 dps.

(2) One microcurie (μCi) [1]=0.000001 curie=3.7×10^4 dps.

[25 FR 10914, Nov. 17, 1960, as amended at 38 FR 29314, Oct. 24, 1973; 39 FR 23990, June 28, 1974; 40 FR 50705, Oct. 31, 1975]

C. Type III cases: Rounding-off changes limiting exposure and dose values.

original text | converted units

§ 33.100

Byproduct material	Col. I curies	Col. II curies	precise Col. I only (GBq)	rounded Col. I only (GBq)
Arsenic-76	1	.01	37	40 or 50
Arsenic-77	10	.1	370	400 or 500
Barium-131	10	.1	370	400 or 500
Barium-140	1	.01	37	40 or 50
Bismuth-210	.1	.001	3.7	4 5
Bromine-82	10	.1	370	400 or 500
Cadmium-109	1	.01	etc.	etc.
Cadmium-115m	1	.01		
Cadmium-115	10	.1		
Calcium-45	1	.01		
Calcium-47	10	.1		
Carbon-14	100	1		
Cerium-141	10	.1		
Cerium-143	10	.1		
Cerium-144	.1	.001		
Cesium-131	100	1		
Cesium-134m	100	1		
Cesium-134	.1	.001		
Cesium-135	1	.01		
Cesium-136	10	.1		
Cesium-137	.1	.001		
Chlorine-36	1	.01		
Chlorine-38	100	1		

§ 20.408

of this chapter or a testing facility as defined in § 50.2(r) of this chapter;

(2) Possess or use byproduct material for purposes of radiography pursuant to Parts 30 and 34 of this chapter;

(3) Possess or use at any one time, for purposes of fuel processing, fabrication, or reprocessing, special nuclear material in a quantity exceeding 5,000 grams of contained uranium-235, uranium-233, or plutonium or any combination thereof pursuant to Part 70 of this chapter; or

(4) Possess or use at any one time, for processing or manufacturing for distribution pursuant to Part 30, 32, or 33 of this chapter, byproduct material in quantities exceeding anyone of the following quantities:

converted units

Radionuclide[1]	*Quantity in curies*	precise (GBq)	rounded (TBq)
Cesium-137	1	37	0.04 or 0.05
Cobalt-60	1	37	0.04 or 0.05
Gold-198	100	3700	4 or 5
Iodine-131	1	37	0.04 or 0.05
Iridium-192	10	370	0.4 or 0.5
Krypton-85	1,000	37,000	40 50
Promethium-147	10	370	0.04 or 0.05
Technetium-99m	1,000	37,000	40 50

[1]The Commission may require, as a license condition, or by rule, regulation or order pursuant to § 20.502, reports from licensees who are licensed to use radionuclides not on this list, in quantities sufficient to cause comparable radiation levels.

§ 140.85 Original text — Converted units

(2) Surface contamination of any offsite property has occurred as the result of a release of radioactive material in the course of transportation and such contamination is characterized by levels of radiation in excess of one of the values listed in column 2 of the following table:

TOTAL SURFACE CONTAMINATION LEVELS [1]

Type of emitter	Column 1 Offsite property, contiguous to site, owned or leased by person with whom an indemnity agreement is executed	Column 2 Other offsite property	Column 2 only
Alpha emission from transuranic isotopes.	3.5 microcuries per square meter.	0.35 microcuries per square meter	12.95 kBq/m^2 [= 13.0]
Alpha emission from isotopes other than transuranic isotopes.	35 microcuries per square meter.	3.5 microcuries per square meter.	129.5 kBq/m^2 [= 130]
Beta or gamma mission.	40 millirads/hour @ 1 cm. (measured through not more than 7 milligrams per square centimeter of total absorber).	4 millirads/hour @ 1 cm. (measured through not more than 7 milligrams per square centimeter of total absorber).	40 μGy/hr at 1 cm

[1] The maximum levels (above background), observed or projected, 8 or more hours after initial deposition.

[33 FR 15999, Oct. 31, 1968, as amended at 40 FR 8794, Mar. 3, 1975]

Title 10—Energy

§ 32.28 Same: table of organ doses.

Part of body	Column I (rem)	Column II (rem)	Column III (rem)	Column I (μSv)	Column II (mSv)	Column III (Sv)
Whole body; head and trunk; active blood-forming organs; gonads; or lens of eye	0.005	0.5	15	50	5	0.15
Hands and forearms; feet and ankles; localized areas of skin averaged over areas no larger than 1 square centimeter	0.075	7.5	200	750	75	2.0
Other organs	0.015	1.5	50	150	15	0.5

[34 FR 6654, Apr. 18, 1969]

Original text | Converted units

§ 20.205

(2) If removable radioactive contamination in excess of 0.01 microcuries (22,000 disintegrations per minute) per 100 square centimeters of package surface is found on the external surfaces of the package, the licensee shall immediately notify[1] the final delivering carrier and, by telephone and telegraph, mailgram or facsimile, the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

367 Bq 500 Bq

TABLE OF EXEMPT AND TYPE A QUANTITIES

Transport group[1]	Exempt quantity limit (in millicuries)	Type A quantity limit (in curies)
I	.01	0.001
II	0.1	0.050
III	1	3
IV	1	20
V	1	20
VI	1	1000
VII	25,000	1000
Special Form	1	20

Column 2 only

I	37 MBq	50 MBq
II	1.85 GBQ	2 GBq
III	111 GBQ	100 GBq
IV,V	740 GBq	750 GBq
VI,VII	37 TBQ	40 TBq
Special	740 GBq	750 GBq

[1]The definitions of "transport group" and "special form" are specified in § 71.4 of this chapter.

[1]The reporting requirements in § 20.205 have been approved by GAO under number B-180 225 (R 0054).

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